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Gosz,
J. R.

THE EFFECTS OF ROAD SALTING ON THE
FUNCTIONING OF A FOREST ECOSYSTEM

Final Report
for
The Effects of Road Salting on the Functioning
of a Forest Ecosystem

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by

James R. Gosz
Biology Department
University of New Mexico

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INTRODUCTION

The increased use of forested areas for winter recreation and second homesites in the mountainous West has resulted in substantial road development, improvement and maintenance activities such as road salting. The use of road salt to maintain ice-free roads has long been an accepted practice, however, the results of inputs of salt on the forest ecosystem are largely unknown.

The overall objective of this study was to quantitatively ascertain the effects of road salting on concentrations of other elements in the forest environment. Specifically, the objectives of this research were to:

- 1) determine the amounts of Na^+ and Cl^- held or lost from forest ecosystems subject to road salting practices;
- 2) determine the interaction of Na^+ and Cl^- with other nutrients in the system;
- 3) develop a preliminary model of forest ecosystem responses to road salting for use in estimating the amount of salt that can be applied under certain conditions without unacceptable damage to the forest ecosystem.

STUDY AREA

The study area is located approximately 17 km northeast of Santa Fe, New Mexico on the Tesuque Watersheds of the Santa Fe National Forest. It extends along Forest Road 101 from Hyde State Park 10 km northeast to the Santa Fe Ski Basin. Rising from 3000 to 3500 m in elevation the road passes through ponderosa pine, mixed conifer, and into spruce-fir vegetational zones. The study

area also includes almost pure stands of aspen (Populus tremuloides Michx.).

During the summer of 1971 the road along which this study was conducted was hard surfaced. The road has been salted yearly during the winter since 1948, however, larger quantities of salt were required after the road was hard surfaced. Extensive foliar damage to the overstory vegetation below the road became apparent in mid-summer of 1972 which led us to initiate our studies.

Our work to date has been performed in aspen stands because of their deciduous nature. Foliar damage reoccurs each year because of conditions during that year. This allows us to evaluate controlling factors more successfully than with a species with persistent foliage which shows the accumulation of damage for a period of years.

Twelve specific study locations were established in early June 1973 along Forest Road 101 with an additional control location (location 13) along an unsalted, unmaintained special use road within the watersheds. In addition, a small gaged aspen watershed is being used to identify nutrient budgets and cycling rates of an undisturbed aspen ecosystem.

Each of the study locations along a road contains three sites: an uphill site (above the road cut) which is not directly affected by road salting; a site whose upper boundary is 8.0 m below the edge of the pavement, and; a site whose upper boundary is 24.0 m below the edge of the pavement. Within each site 15 trees were selected for study and numbered. The characteristics of the 13 study locations are shown in Table 1.

METHODS

Precipitation

Recording precipitation gages (6) and standard storage gages (10) of both the U. S. Forest Service and my research yield detailed data on precipitation over the elevational gradient. Eight polyethylene collectors were used to obtain precipitation samples for chemical analysis.

Throughfall

Five sites were used for throughfall studies with four polyethylene collectors and one standard precipitation gage at each site. Two sites were adjacent to an unsalted road and three were adjacent to Forest Road 101 which is salted during the winter. Samples for chemical analysis were collected during the time leaves were present whenever there was sufficient water for analysis. At collection time the sample bottle was replaced with a clean one and the collecting funnel was rinsed with distilled-demineralized water.

Stream Chemistry

Stream samples were collected at weekly intervals except during the spring melt period when more frequent sampling occurred. Collections were made above the gaging station (above the road) and about 250 m below the road.

Soil and Vegetation

Samples of soil and leaf tissue were made in early summer (June), August, and September. Soil samples were collected from the top 25 cm of the solum.

Analysis

All samples were analyzed for Na^+ , Ca^{++} , Mg^{++} , K^+ and Cl^- . The cations were analyzed by atomic absorption spectrophotometry and Cl^- by a specific ion electrode. Soil samples were routinely analyzed for the following items: water content, gravel, sand, silt, clay, organic matter, and chloride content. Depth of the forest floor was measured during the collections and recorded. Water content was determined gravimetrically (Lull and Reinhart, 1955); gravel was weighed after screening the dried soil samples through a 2 mm soil screen, and; sand, silt and clay contents were determined by the Boyoucouus hydrometer method. Soil organic matter was determined by the weight loss following ignition in a muffle furnace. Soil chloride was extracted in demineralized water in a 2:1 water:soil extract (Sonneveld and Van Den Ende, 1971). Chloride content was measured with a Cl^- specific ion electrode.

Leaf samples were oven dried in a forced air oven at 80°C for 48 hrs and ground in a Wiley mill to pass through a 20-mesh screen. Chloride was extracted with dilute (0.1 N) nitric acid (Cantliffe et al., 1970) and measured with a Cl^- specific ion electrode.

RESULTS

It has been difficult to quantify the actual amount of road salt used on Forest Road 101 since records were not kept by the state highway department. I have estimated the yearly input of road salt from an estimate of application rates and the number of salting trips based on precipitation events. Approximately

1750 kg of sand-salt mixture was applied per mile of road during each salting trip. Chemical analysis of the salt mixture showed it to be 16.7% Cl^- , 9.8% Na^+ , 0.3% $\text{SO}_4^{=}$, 0.13% Ca^{++} , 0.08 K^+ , and 0.015% Mg^{++} . The remainder was mineral sand (less than $\frac{1}{4}$ in. dia.).

Field records show that road salting is related to the number of precipitation events and not the quantity of precipitation. Because of the hard surface as little as 0.05 in. of precipitation caused slick roads and the application of salt. Although the total quantity of snow varied significantly between the winters of 1972-73, 1973-74, and 1974-75, the number of precipitation events was much less variable and, therefore, the number of salting trips each year was similar. I estimate that approximately 40 salting trips were made each winter which results in a total yearly input of 11690 kg Cl^- , 6860 kg Na^+ , 210 kg $\text{SO}_4^{=}$, 91 kg Ca^{++} , 56 kg K^+ , 10 kg Mg^{++} , and 51080 kg sand on each mile of road. These data are used in nutrient budget data later in this report.

Stream Chemistry

A major objective of our research was to evaluate the effect of road salting on water chemistry. The use of water quality data allows quantification of a disturbance to a terrestrial system because of the nutrient and energy linkages that exist between terrestrial and aquatic systems (Likens and Bormann 1974). The effect of a particular land management practice may be evaluated in two ways: 1) the effect of the change of stream parameters on stream organisms (e.g. eutrophication, toxicity) or 2) in terms of the effect on the land area itself (e.g. loss of nutrient capital,

reduced productivity). Water quality analyses themselves (concentrations) can be used in the first method while water quality and water quantity data can estimate total losses of material from a system. This watershed approach to studies of nutrient status is very popular because of its advantages in evaluating inter-relationships between biota, nutrient cycles, hydrologic cycle and energy flow in a single system (Bormann and Likens 1967).

Three drainage systems along Forest Road 101 were used to evaluate the effect of road salt on water quality; south fork of Tesuque Creek, Tesuque Creek, and Rio en Medio. These three systems have gaging stations on the streams above the road (uphill). The effects of the road and the salting practice can be seen in Table 2 and Figures 1-3. Concentrations of Ca^{++} , Mg^{++} , Na^+ , K^+ and Cl^- were significantly higher below the road in all cases with the most significant differences occurring during the spring snow melt period. Of the cations, Ca^{++} and Na^+ showed the greatest change while Cl^- was the major anion affected.

The higher concentrations of all ions in stream water below the road represent a deterioration of water quality, however the increases generally were not large enough to affect down stream organisms. The ion which came closest to pollution levels was Cl^- which reached concentrations in the Rio en Medio as high as 55 mg/l (March 31, 1974) for a brief period. This level does not exceed the tolerance levels for any native fish (trout are affected by 400 mg/l, McKee and Wolf 1963) and of the stream invertebrates only the Tendipedidae or midges have fresh water species with Cl^-

tolerances below 10 mg/l (Tarzwell 1965). It is not known if Tendipedid species have been affected in the streams below the road.

Chlorides are considered to be among the most troublesome anions in irrigation water, however, concentrations of Cl^- in the stream water have not reached levels reported harmful to plants (McKee and Wolf 1963). According to the irrigation water classification shown in McKee and Wolf (1963) the water of all three areas can be used on almost all soils and for almost all crops without detrimental effects.

Nutrient Budgets

The concentration differences shown in Table 2 only reflect the relative degree of change. Expressing the nutrient levels in terms of absolute quantities removed from the system (in kg) or quantities removed per unit area of the system (kg/ha) allows a quantification of the budgets for those nutrients. This allows a comparison of different areas as well as any net accumulation or loss of a particular element. Tables 3, 4, 5, and 6 list the total cation inputs and outputs per unit area for both above and below the road on each drainage. Figures 4, 5 and 6 show the weekly patterns of loss during the course of a year. The budgets for drainage areas above the road represent natural situations (not subject to road salt) with relatively low net change values. Below the road the net change values generally were much greater with significant losses for Ca^{++} , Mg^{++} , and K^+ and significant gains for Na^+ during the 1973-74 water year. The hydrology is very important in determining the quantities removed from the system

as shown in Table 7. Losses during 1972-73 were much larger than those of 1973-74 because of significantly more moisture during 1972-73. The net accumulation of Na^+ during 1973-74 suggests that there was not enough precipitation and stream flow to flush the road salt from the system. The 1974-75 water year was again very moist and I expect significant losses of all elements will occur. Thus, the losses shown for any one year may be a result of inputs from previous years.

The large losses of Na^+ which may occur relative to the natural situation can be explained by road salt application during current or previous years, however, it is not as easy to account for the large losses of Ca^{++} , Mg^{++} , and K^+ . Since there are not large quantities added in road salt the losses must reflect losses from the natural soil system and, therefore, a loss of nutrient capital. Calcium appears to be affected to the greatest degree. The reason would seem to be the mass action replacement of Ca^{++} held to exchange sites in the soil by large quantities of Na^+ added to the system (Brady 1974). Significant quantities of Mg^{++} and K^+ also were lost from the system by the same action but since Ca^{++} is the dominant base cation on the exchange sites it has been affected to the greatest degree. In addition to a loss of nutrient capital the replacement of base elements on exchange sites by Na^+ significantly affects the soil itself. The effects of Na^+ on soil physical properties result primarily from the breakdown of the granular soil structure. Calcium and Mg^{++} in the proper proportions maintain soil in good condition of tilth and structure because their divalent charge and low hydration cause them to be tightly

held by soil colloids enhancing the coagulation of colloid particles. Monovalent Na^+ which is highly hydrated is not tightly held by colloid particles permitting individual particles to repel each other and to stay in dispersion (Brady 1974). In most normal soils Ca^{++} and Mg^{++} are the principal cations held by the soil in replaceable or exchangeable form, with Na^+ consisting of a small percentage (i.e. 3 to 7%, McKee and Wolf 1963). An increase of the percentage Na^+ to as much as 12 or 15% causes the granular soil structure to begin to break down when the soil is moistened. Various changes take place resulting in the sealing of pores and a decrease in soil permeability. With further increases in the Na^+ percentage, the soil continues to deteriorate and its pH increases to the level of alkali soils (McKee and Wolf 1963).

Vegetation requires Ca^{++} in relatively large quantities in relation to Na^+ or other base elements (Rodin and Basilevich 1967) and the replacement of Ca^{++} by Na^+ on the exchange sites in soil must reduce the ability of vegetation to obtain Ca^{++} as well as other elements. It is difficult to predict whether this has more effect than deterioration of the soil physical characteristics or Na^+ and Cl^- toxicity, however, the combination of all of these significantly damages vegetation (Piatt and Krause 1974).

Nutrient Cycling

The large additions of Na^+ and Cl^- and resulting large losses of Ca^{++} , Mg^{++} and K^+ can be expected to significantly alter the nutrient cycling characteristics of a natural system. The degree to which this happens is related to the natural buffering capacity of the soil system and the ability of the vegetation to tolerate

or reduce stress. Since the vegetation below the road exhibits foliar damage an analysis of nutrient cycling characteristics might suggest whether reduced nutrient capital is involved or Cl^- toxicity.

The greatest foliar damage occurs immediately below the road. Table 8 shows a progressive increase in damage from June through September in almost all sites 8.0 m below the road. Foliar damage did not occur above the road or at 24.0 m below the road. Table 9 identifies changes in leaf Cl^- levels throughout the summer at the various study sites and shows that the Cl^- levels in plant tissue are highest at the study site 8.0 m below the road. In fact leaf Cl^- content was significantly correlated with damage. All sites including the control showed a progressive increase in leaf Cl^- content throughout the summer, however, foliar damage only occurred when levels reached 0.5% of the oven-dried tissue weight. This strongly suggests that Cl^- toxicity is the causal agent, however, damage did not always occur when concentrations reached 0.5%. Some leaf tissues had Cl^- levels of 1.2% without visible damage. At this point in our studies it appears that adequate water can modify Cl^- caused damage.

Tables 10, 11, 12 and 13 show concentrations of Ca^{++} , Mg^{++} , K^+ and Na^+ in leaf tissue during June. Of these elements only K^+ seemed to be influenced adversely. The concentration of K^+ in leaf tissue was significantly lower in vegetation on the 8.0 m study site than at 24.0 m below the road or above the road.

Although increased levels of Cl^- were found in vegetation subject to road salt the Na^+ levels remained normal. This suggests either the ability to reduce Na^+ uptake or rapidly lose Na^+

(through leaching) to maintain levels near normal.

Studies of throughfall help to resolve questions raised by leaf tissue nutrient concentrations. Table 14 shows quantities of nutrients leached from vegetation on control sites and sites subject to road salt. Calcium and Mg^{++} showed no significant differences in leaching rates, however, Na^+ increased significantly in the throughfall below vegetation subject to road salt and K^+ decreased significantly. This data supports the K^+ data on leaf tissue concentrations. Since K^+ is very mobile in leaf tissue and easily leached, lower leaf concentrations should cause lower quantities in throughfall. The increased levels of Na^+ in throughfall suggest that larger amounts of Na^+ are taken up by vegetation subject to road salt (Fig. 7), however, leaching removes Na^+ to the degree that leaf tissue concentrations are normal. The vegetation also may be able to selectively exclude Na^+ since the amount taken up is very small in relation to the amount of Na^+ supplied in salt. This does not appear to be the case for Cl^- . Chloride levels in throughfall for sites subject to road salt are not significantly different than those of control sites. They also are very similar to concentrations in precipitation which suggests that Cl^- is not readily leached from vegetation. Previous data identifies that the Cl^- concentration gradually increases in leaf tissue causing values as high as 2.9% on sites subject to salting. This build up during the growing season must be related to levels of Cl^- in the soil. As Cl^- is an anion and as most soils have an extremely low anion-exchange capacity, essentially all of the Cl^- present in the soil is found in the soil water (Brady 1974).

Chloride concentration is probably the most important variable in determining the rate of Cl^- uptake by vegetation for the simple reason that roots are more likely to come in contact with the ion in a concentrated solution than in a dilute solution. Chloride concentration is a function of two variables, the amount of Cl^- present in the soil and the amount of water present, therefore, $\text{meq Cl}^-/100 \text{ g of soil}$, g water/g soil , and $\text{mg Cl}^-/\text{g water}$ will be discussed.

Comparisons of Cl^- concentrations ($\text{mg Cl}^-/\text{g HOH}$ ~~$\text{meq Cl}^-/100 \text{ g soil}$~~) in the 8 and the 24 m experimental sites show a consistent pattern of increasing concentration from collection to collection (Table 15). Maximum values occurred in the September samples for all of the experimental sites. The increase in Cl^- concentration must have been caused by the increased Cl^- content in the 8 m sites as the water content remained constant. In both the uphill and the 24 m sites the increase in concentration was caused both by an increase in Cl^- content and by the depletion of soil water. The control location showed basically the same pattern as that found in the experimental locations. Maximum concentrations were found in September, however, the differences found in the June and August samples were not significant.

Table 15 also illustrates the relationships of these variables between sites. Chloride content was actually lower in the 8 m sites than in the other two sites in the June samples (probably as the result of leaching during spring snow melt), but because of the lower water content in the 8 m sites, the Cl^- concentrations

were statistically equal. By the August collection sufficient Cl^- had entered the 8 m sites that all sites contained the same amount of Cl^- . In this collection the significantly lowered soil water content in the 8 m sites resulted in significantly higher Cl^- concentrations in these sites than in the others. In the September samples the interaction of a higher Cl^- content and a lowered soil water content again resulted in a significantly higher Cl^- concentration in the 8 m sites than in either the uphill or the 24 m sites. In the control location the only significant differences of Cl^- concentration which were found were in the August collections at which time the 8 and 24 m contained a significantly greater concentration than the uphill site. This difference was due to the higher Cl^- content of these sites at the time of collection.

Winter road maintenance practices include the application of road salt as a sand/salt mixture. Sufficient sand has been added that the sand which does enter the 8 m sites has resulted in a significant change in soil texture. This increase in sand is marked by the significant decrease in the percentage of both silt and clay. As the finer soil particles are most active in maintaining soil water (Brady 1974) even with an equal input of precipitation, the 8 m sites will be drier as they are unable to hold water. Winter snow is plowed from the road into the below the road sites, therefore these sites may actually receive more water than the above the road sites. As we have seen, however, the 8 m sites are consistently drier than the other sites and one of the major reasons is the amount of sand present.

While the previous discussion has identified some definite effects due to road salting there is a large amount of variability from site to site no doubt as a result of the large number of environmental variables. Tables 16, 17, and 18 show correlation matrices for as many as 20 of these variables. It is difficult to summarize the differences in these three tables but a general statement can be made about the site most significantly affected; 8.0 m below the road. As a result of the large quantities of salt sand, and gravel ($< \frac{1}{4}$ " dia.) applied to the area below the road the 8.0 m site has pronounced high levels of sand and gravel, low levels of silt, clay, soil organic matter, and litter. These factors cause low soil moisture and forb cover and a high Cl^- concentration in leaf tissue. There is also a suggestion that low K^+ concentrations in leaf tissue are associated with high Cl^- concentrations, however, the negative correlation is just below the .05 significance level. A more realistic explanation may be that lower levels of soil organic matter and litter reduce the amount of exchangeable K^+ in the soil and as a result less can be absorbed. This is supported by the resulting lower levels of K^+ in throughfall. It is not known if the lower levels of K^+ reflect a K^+ deficiency. Unfortunately the symptoms of K^+ deficiency are similar to those of Cl^- toxicity and water deficiency (Gilbert 1957). Gilbert (1957) suggests that low levels of K^+ may cause plants to absorb larger quantities of Na^+ which may explain the increased Na^+ content in throughfall of vegetation subject to road salt. This point may be especially significant since most vegetation seems to have the ability to exclude high levels of Na^+ .

The above discussion suggests that the modification of the soil characteristics through the addition of sand and gravel, as well as the structure breakdown effects of Na^+ , may be equally or more important than the direct effects of the salt on vegetation. This makes it very difficult to develop any model of forest ecosystem responses to salting by itself. It is obvious that the combination of sand and salt causes significant vegetation damage and a suggestion to reduce the amount of salt (by increasing the proportion of sand in the mixture) may or may not reduce damage. It may prove to be better to reduce the sand in the mixture since the salt can be flushed from the system but the sand cannot. The only clear recommendation is the complete stoppage of sand/salt application. Methods of mass transportation or the requirement of snow tires or chains should be investigated since these methods can allow access with only snow plowing activities.

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Table 1

CHARACTERISTICS OF STUDY LOCATIONS ESTABLISHED JUNE 1973

Location #	Shoulder Width (m)			Distance to trees in 8 m sites			Aspect	Elevation (m)	Mean Slope (°)
	Mean	Max.	Min.	Mean	Max.	Min.			
1	0.91	1.22	0.61	9.14	11.58	6.22	N	2957	33
2	1.03	3.35	0.00	11.39	16.15	8.38	NE	2996	30
3	0.00	0.00	0.00	8.24	10.55	5.94	SW	3033	34
4	3.76	3.96	3.05	8.87	10.55	7.86	W	3033	25
5	4.78	5.27	4.45	8.70	10.55	6.71	WNW	3002	14
6	1.00	1.10	0.82	9.50	13.11	5.88	WSW	2984	37
7	0.19	0.49	0.00	7.31	9.02	5.21	W	2987	34
8	7.51	8.69	6.52	9.60	12.04	8.08	W	3014	8
9	1.07	2.32	0.00	8.76	12.50	5.40	WSW	3018	24
10	0.43	1.34	0.00	8.83	11.16	6.28	W	3078	29
11	2.20	2.44	1.77	9.29	11.16	7.71	WSW	3130	30
12	2.90	4.18	2.26	9.69	12.07	7.83	W	3170	38
13	*	*	*	8.41	9.62	7.87	S	3109	30

* Location 13 is along an unpaved special use road.

Table 2. Yearly average concentrations of nutrients in stream water above and below the road on the Rio en Medio.

	Concentration (mg/l)				
	<u>Ca⁺⁺</u>	<u>Mg⁺⁺</u>	<u>Na⁺</u>	<u>K⁺</u>	<u>Cl⁻</u>
Above road					
1972-73	3.23	0.68	1.90	0.57	0.3
1973-74	2.94	0.70	1.97	0.59	0.3
1974-75	2.76	0.64	1.71	0.54	-
Below road					
1972-73	5.53	1.15	6.30	0.80	11.9
1973-74	5.20	1.16	5.02	0.93	17.1
1974-75	5.76	1.28	5.90	1.02	-

Table 3. Calcium budgets for three study areas during the 1973-74 water year. Values are kg/ha.

	<u>Precip. Input</u>	<u>Salt Input</u>	<u>Stream Output</u>	<u>Net Change</u>
<u>Ca⁺⁺</u>				
Rio en Medio				
above road	6.3	-	8.0	-1.7
below road	6.4	5.7	20.6	-8.5
Tesuque Creek				
above road	6.5	-	4.8	+1.7
below road	6.2	24	100	-69.8
South Fork Tesuque Crk				
above road	6.2	-	3.8	+2.4
below road	6.1	22	277	-248.9

Table 4. Magnesium budgets for three study areas during the 1973-74 water year. Values are kg/ha.

	<u>Precip.</u> <u>Input</u>	<u>Road</u> <u>Salt</u> <u>Input</u>	<u>Stream</u> <u>Output</u>	<u>Net</u> <u>Change</u>
<u>Mg⁺⁺</u>				
Rio en Medio				
above road	1.0	-	1.9	-0.9
below road	0.9	0.9	6.0	-4.2
Tesuque Creek				
above road	0.9	-	1.6	-0.7
below road	0.8	2.5	46.0	-42.7
S. Fork Tesuque Creek				
above road	0.8	-	1.5	-0.7
below road	0.8	1.7	75.0	-72.5

Table 5. Sodium budgets for three study areas during the 1973-74 water year. Values are kg/ha.

<u>Na⁺</u>	<u>Precip. Input</u>	<u>Road Salt Input</u>	<u>Stream Output</u>	<u>Net Change</u>
Rio en Medio				
above road	0.8	-	5.3	-4.5
below road	0.7	408	52.7	+354.6
Tesuque Creek				
above road	0.7	-	3.6	-2.9
below road	0.8	1801	359.0	+1441.2
S. Fork Tesuque Creek				
above road	1.2	-	3.1	-1.9
below road	1.2	1600	222.0	+1376.8

Table 6. Potassium budgets for three study areas during the 1973-74 water year. Values are kg/ha.

	<u>Precip.</u> <u>Input</u>	<u>Road</u> <u>Salt</u> <u>Input</u>	<u>Stream</u> <u>Output</u>	<u>Net</u> <u>Change</u>
<u>K⁺</u>				
Rio en Medio				
above road	1.1	-	1.6	-0.5
below road	1.2	3.3	4.1	+0.4
Tesuque Creek				
above road	1.4	-	1.3	+0.1
below road	1.4	15.0	18.0	-1.6
S. Fork Tesuque Creek				
above road	1.4	-	0.8	+0.6
below road	1.4	13.0	30.0	-15.6

Table 7. Nutrient budgets for above and below the road of the Rio en Medio area during a two-year period. Values are expressed in kg/ha.

	1972-73				1973-74			
	<u>Precip.</u> <u>Input</u>	<u>Road</u> <u>Salt</u> <u>Input</u>	<u>Stream</u> <u>Output</u>	<u>Net</u> <u>Change</u>	<u>Precip.</u> <u>Input</u>	<u>Road</u> <u>Salt</u> <u>Input</u>	<u>Stream</u> <u>Output</u>	<u>Net</u> <u>Change</u>
<u>Ca⁺⁺</u>								
above road	7.2	-	24.5	-17.3	6.3	-	8.0	-1.7
below road	7.2	5.7	240.6	-227.7	6.4	5.7	20.6	-8.5
<u>Mg⁺⁺</u>								
above road	0.6	-	5.0	-4.4	1.0	-	1.9	-0.9
below road	0.6	0.9	50.9	-51.4	1.0	0.9	6.0	-4.1
<u>K⁺</u>								
above road	2.1	-	4.3	-2.2	1.1	-	1.6	-0.5
below road	2.0	3.3	35.3	-30.0	1.2	3.3	4.1	+0.4
<u>Na⁺</u>								
above road	1.0	-	13.6	-12.6	0.8	-	5.3	-4.5
below road	1.0	408.2	482.4	-73.2	0.8	408.2	52.7	+356.3

Table 8

PERCENTAGE OF TREES SHOWING DAMAGE IN 8.0 m STUDY SITES

<u>Location</u>	<u>June</u>	<u>August</u>	<u>September</u>
1	0	0	30
2	0	10	50
3	0	0	0
4	0	0	50
5	0	10	30
6	0	0	10
7	0	0	30
8	0	20	60
9	0	0	0
10	0	0	10
11	0	0	30
12	0	0	20
13 ¹	0	0	0

1. Location 13 is along an unpaved, unsalted special use road.

Table 9. Comparisons of chloride content of vegetation samples during the growing season for study sites. Values are percentage of oven-dry weight*.

	<u>Uphill</u>	<u>8.0 m below road</u>	<u>24.0 m below road</u>
June	0.084 b**	0.216 a	0.094 b
August	0.188 b	0.748 a	0.224 b
September	0.282 b	1.218 a	0.350 b

* Data was transformed to arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different ($P < .05$). Values are the mean of 120 samples.

Table 10. Comparisons of Calcium Content in June Vegetation Samples (Percentage* of Oven Dry Weight).

<u>Location</u>	<u>Uphill</u>	<u>8.0 m</u>	<u>24.0 m</u>
1	1.24 a**	1.09 a	1.29 a
2	1.57 a	1.10 b	1.23 b
3	1.12 a	0.87 b	0.89 b
4	1.03 b	1.06 ab	1.19 a
5	1.15 ab	1.21 a	1.05 b
6	0.92 a	0.84 a	0.85 a
7	1.03 a	1.00 a	1.08 a
8	1.98 a	0.88 a	0.94 a
9	1.08 a	1.01 a	0.98 a
10	1.18 a	1.15 a	1.17 a
11	1.03 a	1.13 a	1.19 a
12	0.68 b	0.77 a	0.74 ab
Mean	1.08 a***	1.01 a	1.05 a
13 ¹	0.57 b	0.81 a	0.95 a

* Percentage data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

¹ Location 13 is along an unsalted unmaintained access road.

Table 11. Comparisons of Magnesium Content in June Vegetation Samples (Percentage* of Oven Dry Weight).

<u>Location</u>	<u>Uphill</u>	<u>8.0 m</u>	<u>24.0 m</u>
1	0.24 a**	0.22 a	0.24 a
2	0.32 a	0.25 b	0.26 b
3	0.24 a	0.23 ab	0.22 b
4	0.28 a	0.25 b	0.28 a
5	0.22 b	0.21 b	0.28 a
6	0.21 a	0.18 b	0.21 a
7	0.21 a	0.22 a	0.22 a
8	0.23 a	0.22 a	0.24 a
9	0.27 a	0.23 b	0.23 b
10	0.24 ab	0.23 b	0.25 a
11	0.22 a	0.25 a	0.23 a
12	0.28 a	0.26 a	0.28 a
Mean	0.25 a***	0.23 a	0.25 a
13 ¹	0.15 b	0.18 b	0.22 a

* Percentage data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

¹ Location 13 is along an unsalted unmaintained access road.

Table 12. Comparisons of Potassium Content in June Vegetation Samples (Percentage* of Oven Dry Weight).

<u>Location</u>	<u>Uphill</u>	<u>8.0 m</u>	<u>24.0 m</u>
1	2.35 ab**	2.12 b	2.49 a
2	2.53 a	1.67 b	1.87 b
3	2.07 b	2.63 a	2.38 ab
4	2.45 a	1.64 b	2.29 a
5	2.09 b	1.79 b	2.99 a
6	2.43 a	1.84 c	2.06 b
7	2.72 a	2.36 b	2.36 b
8	2.60 a	1.87 b	2.68 a
9	2.52 a	2.17 b	2.31 b
10	2.25 a	2.02 b	2.10 ab
11	1.87 b	2.38 a	1.95 b
12	2.10 a	1.78 b	2.06 a
Mean	2.33 a***	2.02 b	2.31 a
13 ¹	1.35 b	1.77 a	1.90 a

* Percentage data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

¹ Location 13 is along an unsalted, unmaintained access road.

Table 13. Comparisons of Sodium Content in June Vegetation Samples (Percentage* of Oven Dry Weight).

<u>Location</u>	<u>Uphill</u>	<u>8.0 m</u>	<u>24.0 m</u>
1	0.03 a**	0.02 b	0.02 b
2	0.02 a	0.03 a	0.04 a
3	0.04 a	0.01 b	0.01 b
4	0.02 b	0.08 a	0.06 a
5	0.06 a	0.06 a	0.02 b
6	0.02 a	0.01 b	0.01 b
7	0.02 a	0.02 a	0.02 a
8	0.01 a	0.02 a	0.02 a
9	0.02 a	0.03 a	0.02 a
10	0.02 a	0.02 a	0.02 a
11	0.02 a	0.02 a	0.02 a
12	0.02 a	0.02 a	0.02 a
Mean	0.02 a***	0.03 a	0.02 a
13 ¹	0.02 a	0.02 a	0.02 a

* Percentage data was transformed to its arcsin prior to analysis.

** Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of ten samples.

*** Means not followed by the same letter are significantly different at the 0.05 level. Values are the mean of data from locations 1-12.

¹ Location 13 is along an unsalted, unmaintained access road

Table 14. Quantities of nutrients leached from aspen vegetation (kg/ha) during the growing season. Control sites are not subject to road salt.

	<u>Control</u>	<u>Subject to Road Salt</u>
Ca ⁺⁺	2.89 a*	2.67 a
Mg ⁺⁺	0.83 a	0.84 a
Na ⁺	0.00 a	0.34 b
K ⁺	13.85 a	12.34 b

* Values within a row not followed by the same letter are significantly different ($P < .05$).

Table 15. Soil chloride and water content of study sites.

Variable	Data	Above Road Cut	8.0 m Below Pavement	24.0 m Below Pavement
June				
Chloride content (meq Cl/100 g soil)	Locations 1-12	0.060 a*	0.045 b	0.060 a
Water content (g HOH/g soil)	Locations 1-12	0.138 a*	0.086 b	0.137 a
Chloride Concen- tration (mg Cl/g HOH)	Locations 1-12	0.170 a	0.193 a	0.173 a

August				
Chloride content (meq Cl/100 g soil)	Locations 1-12	0.119 a*	0.124 a	0.123 a
Water content (g HOH/g soil)	Locations 1-12	0.125 a*	0.081 b	0.120 a
Chloride Concen- tration (mg Cl/g HOH)	Locations 1-12	0.396 b*	0.548 a	0.390 b

September				
Chloride content (meq Cl/100 g soil)	Locations 1-12	0.117 b*	0.152 a	0.128 ab
Water content (g HOH/g soil)	Locations 1-12	0.099 a*	0.076 b	0.108 a
Chloride Concen- tration (mg Cl/g HOH)	Locations 1-12	0.500 b*	0.855 a	0.468 b

* Values within a row not followed by the same letter are significantly different at the 0.05 level. Values are the mean of sixty samples (five per location).

Table 16. Correlations of uphill June Vegetation Samples with other measured parameters.

	Tissue Concentration					DBH	Gravel	Sand	Silt	Clay	OM	Litter	Forb Cover	Soil (Cl)	Soil HOH	Elev.	Aspect
	Ca	Mg	Na	K	Cl												
Tissue Conc. Ca	1.000	0.354	0.196	0.190	0.645*	0.158	0.187	-0.020	-0.373	0.770**	-0.388	0.079	0.206	-0.296	0.291	-0.521	-0.630*
Mg		1.000	-0.224	0.144	0.341	0.481	0.022	-0.020	-0.030	0.352	-0.342	-0.393	-0.103	0.129	-0.114	0.160	-0.348
Na			1.000	-0.470	0.331	0.246	0.029	-0.404	0.190	0.387	-0.169	0.255	0.197	-0.135	0.225	-0.203	0.063
K				1.000	0.017	0.066	-0.109	-0.116	-0.030	0.408	-0.050	-0.461	0.037	0.148	0.007	-0.633*	-0.115
Cl					1.000	0.128	0.063	-0.010	-0.124	0.484	-0.040	-0.196	0.071	0.123	0.105	-0.231	-0.297
DBH						1.000	0.423	-0.388	0.403	0.439	-0.097	0.008	0.030	-0.158	0.031	-0.150	-0.060
Gravel							1.000	0.404	-0.319	-0.030	-0.006	0.195	0.275	0.162	-0.515	-0.113	-0.478
Sand								1.000	-0.834**	-0.509	-0.084	-0.157	0.215	0.171	-0.654	0.156	-0.553
Silt									1.000	0.057	0.384	0.255	-0.319	-0.040	0.509	0.179	-0.365
Clay										1.000	-0.487	-0.122	0.215	-0.227	0.355	-0.717	-0.365
OM											1.000	0.231	-0.476	0.111	0.264	0.394	0.685*
Litter												1.000	0.023	-0.402	0.495	0.133	0.284
Forb													1.000	0.180	-0.311	-0.509	-0.497
Soil (Cl)														1.000	-0.619*	0.156	0.028
Soil HOH															1.000	-0.092	0.475
Elev.																1.000	0.407
Aspect																	1.000

* $\alpha_{.05} = .576$ ** $\alpha_{.01} = .708$

Table 17. Correlations of 8.0 m June Vegetation Samples with other measured parameters.

	Tissue Concentration					DBH	Gravel	Sand	Silt	Clay	OM	Litter	Forb Cover	Soil (Cl)	Soil HOH	Elev.	Aspect	Slope	Distance	
	Ca	Mg	Na	K	Cl														Shoulder Width	to Tree
Tissue Conc. Ca	1.000	0.092	0.472	-0.050	0.294	-0.288	-0.669*	-0.387	0.349	0.494	0.410	0.408	0.194	0.456	0.419	-0.200	-0.192	-0.303	-0.050	-0.020
Mg		1.000	0.236	-0.050	0.653*	-0.224	0.419	0.475	-0.527	-0.174	-0.428	-0.278	-0.185	0.207	-0.393	0.646*	-0.040	0.109	0.031	0.270
Na			1.000	-0.537	0.532	0.258	-0.123	-0.290	0.294	0.213	0.224	0.236	0.105	0.482	-0.030	-0.092	0.244	-0.437	0.414	-0.030
K				1.000	-0.558	-0.724**	-0.380	0.076	-0.069	-0.079	0.038	0.298	0.380	-0.403	0.424	0.038	-0.008	0.286	-0.496	-0.603*
Cl					1.000	0.186	0.185	0.043	-0.014	0.208	-0.191	-0.097	-0.271	0.692*	-0.328	0.080	-0.224	-0.020	0.091	0.525
DBH						1.000	0.361	-0.314	0.327	0.161	0.218	0.009	-0.246	0.171	-0.105	-0.222	-0.040	-0.190	0.496	0.419
Gravel							1.000	0.611*	-0.586*	-0.610*	-0.619*	-0.715**	-0.391	-0.352	-0.722**	0.583*	0.244	-0.076	0.492	0.461
Sand								1.000	-0.990**	-0.826**	-0.828**	-0.806**	-0.544	-0.408	-0.689*	0.596*	0.162	0.184	-0.060	0.179
Silt									1.000	0.740**	0.848**	0.809**	0.567	0.305	0.711**	-0.599*	-0.050	-0.261	0.127	-0.247
Clay										1.000	0.564	0.615*	0.343	0.725**	0.454	-0.471	-0.593*	0.144	-0.239	0.131
OM											1.000	0.857**	0.473	0.166	0.891**	-0.322	0.162	-0.072	-0.040	-0.437
Litter												1.000	0.464	0.293	0.864**	-0.427	0.018	-0.004	-0.127	-0.566
Forb Cover													1.000	-0.175	0.574	-0.050	0.268	-0.200	-0.030	-0.360
Soil (Cl)														1.000	-0.030	-0.350	-0.578*	0.241	-0.245	0.285
Soil HOH															1.000	-0.294	0.124	-0.010	-0.225	-0.537
Elev.																1.000	0.402	0.209	0.094	0.102
Aspect																	1.000	-0.310	0.388	-0.506
Slope																		1.000	-0.811**	-0.040
Shoulder Width																			1.000	0.201
Distance to Tree																				1.000

* $\alpha_{.05} = .576$ ** $\alpha_{.01} = .708$

Table 18. Correlations of 24.0 m June Vegetation Samples with other measured parameters.

	Tissue Concentration					DBH	Gravel	Sand	Silt	Clay	OM	Litter	Forb Cover	Soil (Cl)	Soil HOH	Elev.	Aspect	Slope
	Ca	Mg	Na	K	Cl													
Tissue Conc. Ca	1.000	0.125	0.495	-0.060	0.470	-0.050	-0.333	-0.080	-0.076	0.344	-0.177	0.290	-0.311	0.018	-0.170	-0.311	-0.502	-0.097
Mg		1.000	0.609	0.171	0.579	-0.086	0.216	0.274	-0.254	-0.318	-0.340	0.051	0.317	0.644	-0.502	0.317	0.175	-0.288
Na			1.000	-0.149	0.841	0.098	0.005	0.124	-0.172	-0.050	-0.331	0.217	-0.030	0.518	-0.537	-0.030	-0.066	-0.168
K				1.000	-0.412	0.010	-0.453	-0.737	0.679	0.406	0.635	-0.263	-0.425	-0.195	0.524	-0.425	0.290	-0.681
Cl					1.000	0.222	0.166	0.360	-0.393	-0.103	-0.606	0.047	0.001	0.597	-0.735	0.001	-0.349	0.071
DBH						1.000	0.207	-0.111	-0.082	0.610	-0.117	-0.584	0.050	-0.287	-0.256	-0.573	-0.356	0.364
Gravel							1.000	0.559	-0.465	-0.328	-0.500	0.182	0.629	-0.075	-0.368	-0.573	0.060	0.560
Sand								1.000	-0.944	-0.538	-0.651	0.069	0.684	0.415	-0.663	0.684	-0.145	0.625
Silt									1.000	0.277	0.642	0.075	-0.474	-0.348	0.743	-0.474	0.339	-0.639
Clay										1.000	0.210	-0.432	-0.825	-0.405	0.071	-0.825	-0.530	0.011
OM											1.000	0.001	-0.297	-0.372	0.853	-0.297	0.498	-0.576
Litter												1.000	0.516	0.039	0.189	0.516	0.416	-0.030
Forb Cover													1.000	-0.318	0.128	-0.194	0.066	0.137
Soil (Cl)														1.000	-0.609	0.289	0.061	-0.147
Soil HOH															1.000	-0.183	0.493	-0.428
Elev.																1.000	-0.310	0.209
Aspect																	1.000	-0.310
Slope																		1.000

* $\alpha_{.05} = .576$ ** $\alpha_{.01} = .708$

FIGURE LEGEND

- Figure 1. Weekly concentrations (mg/l) of Ca^{++} in the South Fork of Tesuque Creek above and below a road subject to winter road salting. Note the different scales for above and below the road. The one-year period is the 1974-75 water year.
- Figure 2. Weekly concentrations (mg/l) of K^+ and Mg^{++} in the South Fork of Tesuque Creek above and below a road subject to winter road salting. The one-year period is the 1974-75 water year.
- Figure 3. Weekly concentrations (mg/l) of Na^+ in the South Fork of Tesuque Creek above and below a road subject to winter road salting. The one-year period is the 1974-75 water year.
- Figure 4. Total Ca^{++} (kg/ha) exported from above and below the road in the South Fork of Tesuque Creek during the 1973-74 water year. Note the different scales for above and below the road.
- Figure 5. Total K^+ and Mg^{++} (kg/ha) exported from above and below the road in the South Fork of Tesuque Creek during the 1973-74 water year. Note the different scales for above (dashed line) and below (solid line) the road.
- Figure 6. Total Na^+ (kg/ha) exported from above and below the road in the South Fork of Tesuque Creek during the 1973-74 water year. Note the different scales for above and below the road.

Figure 7. Mean Na^+ concentration ($\pm$ standard error) of the rain (n=4) and throughfall beneath trees subject to road salt (n=12) and trees not subject to road salt (n=8).

Figure 1.

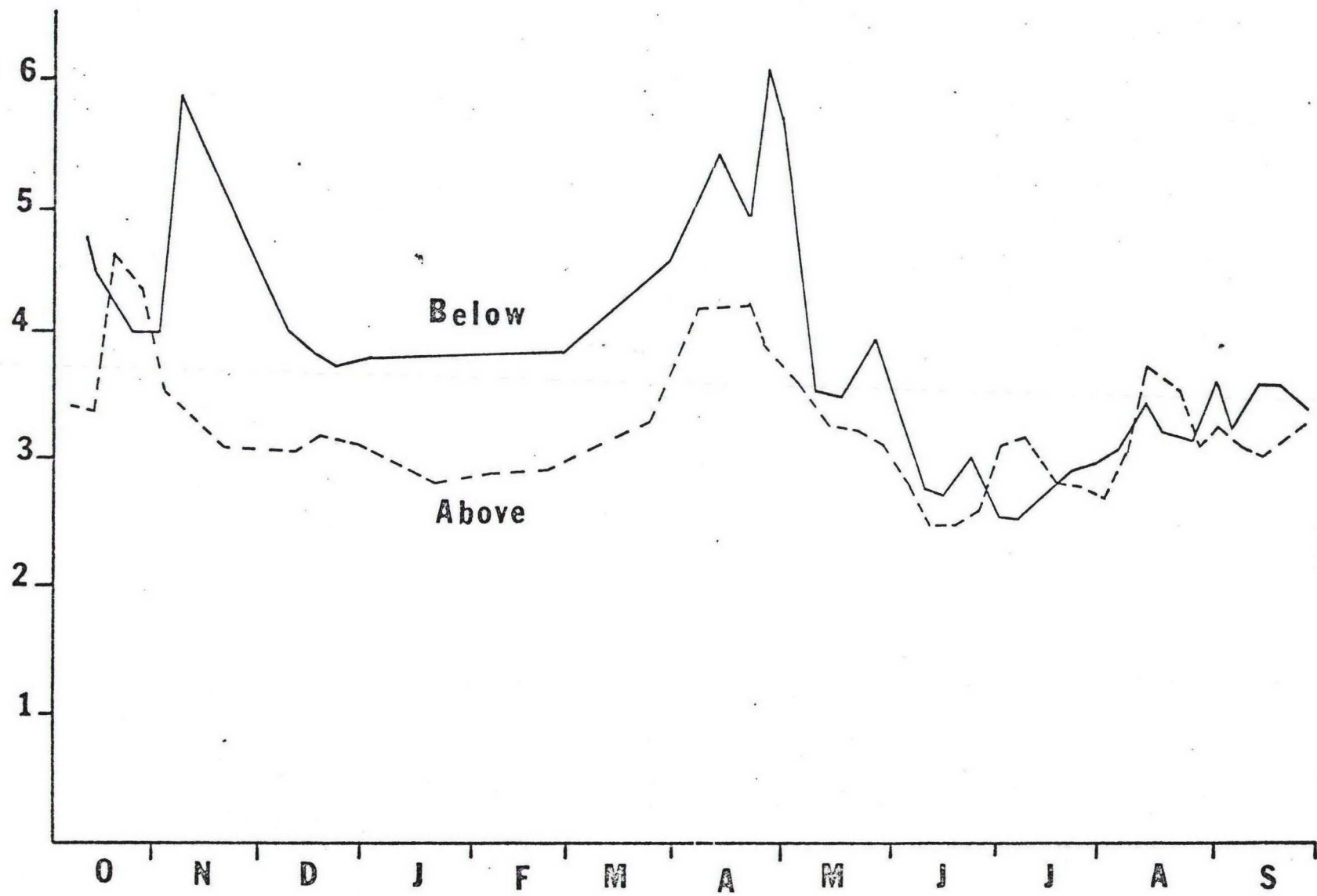


Figure 2.

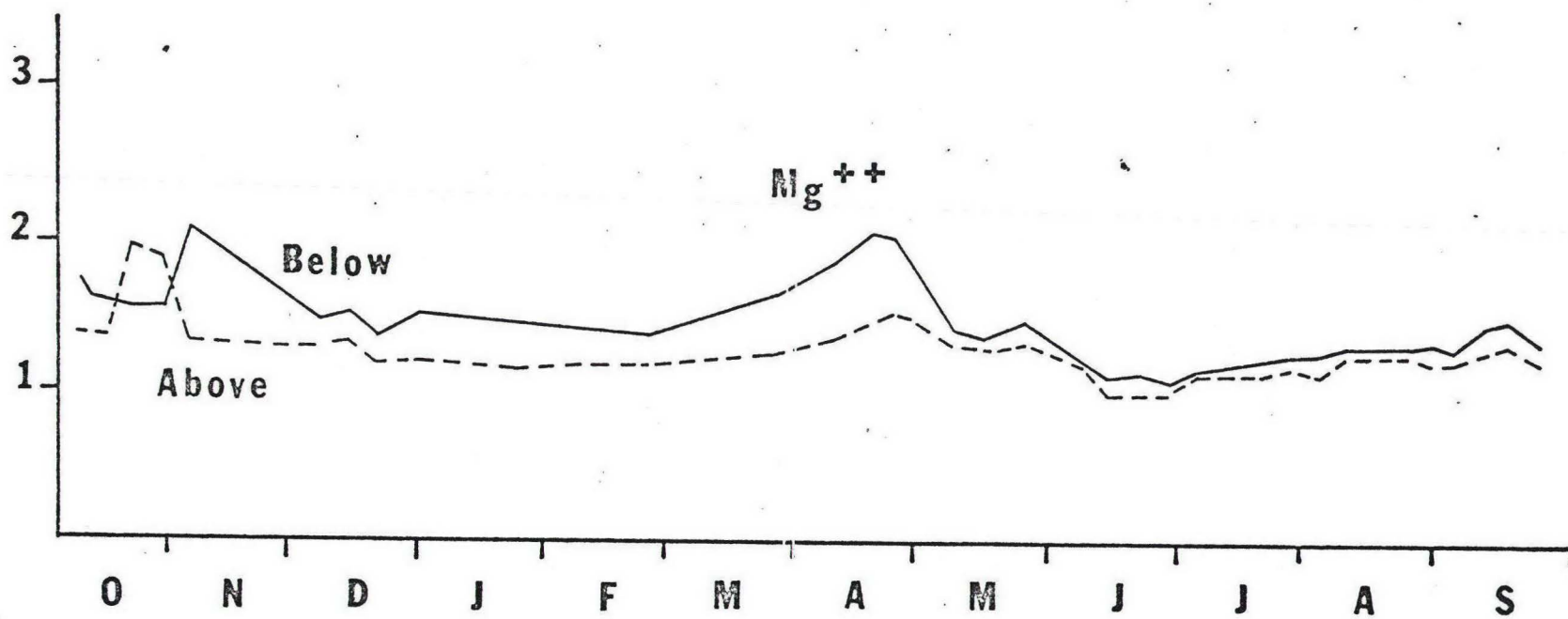
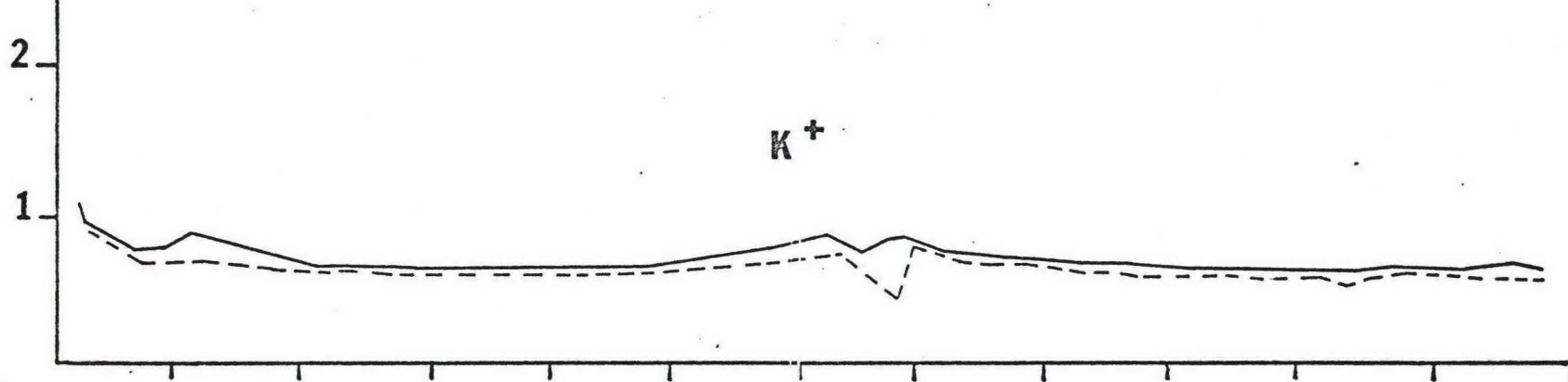


Figure 3.

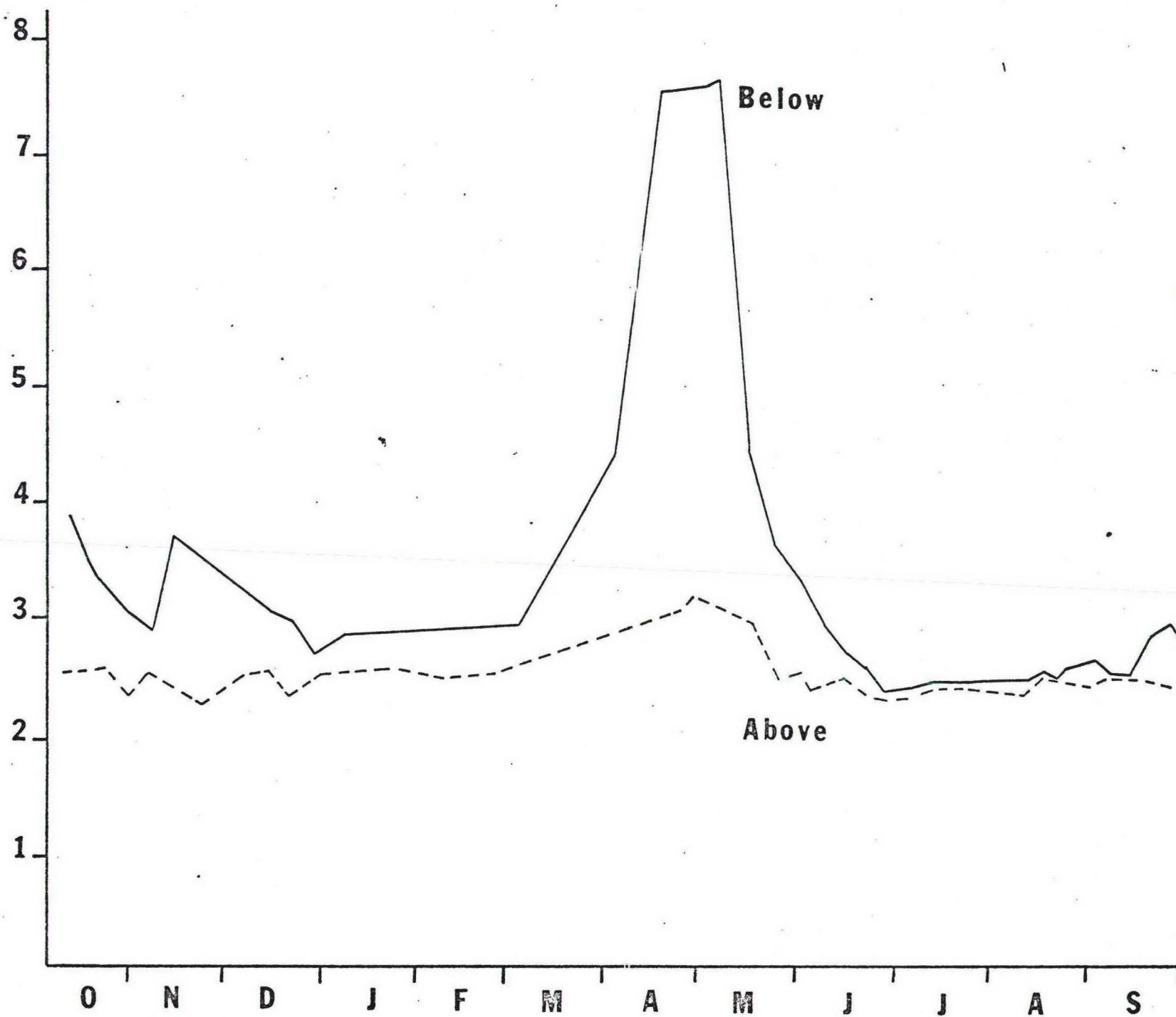


Figure 4.

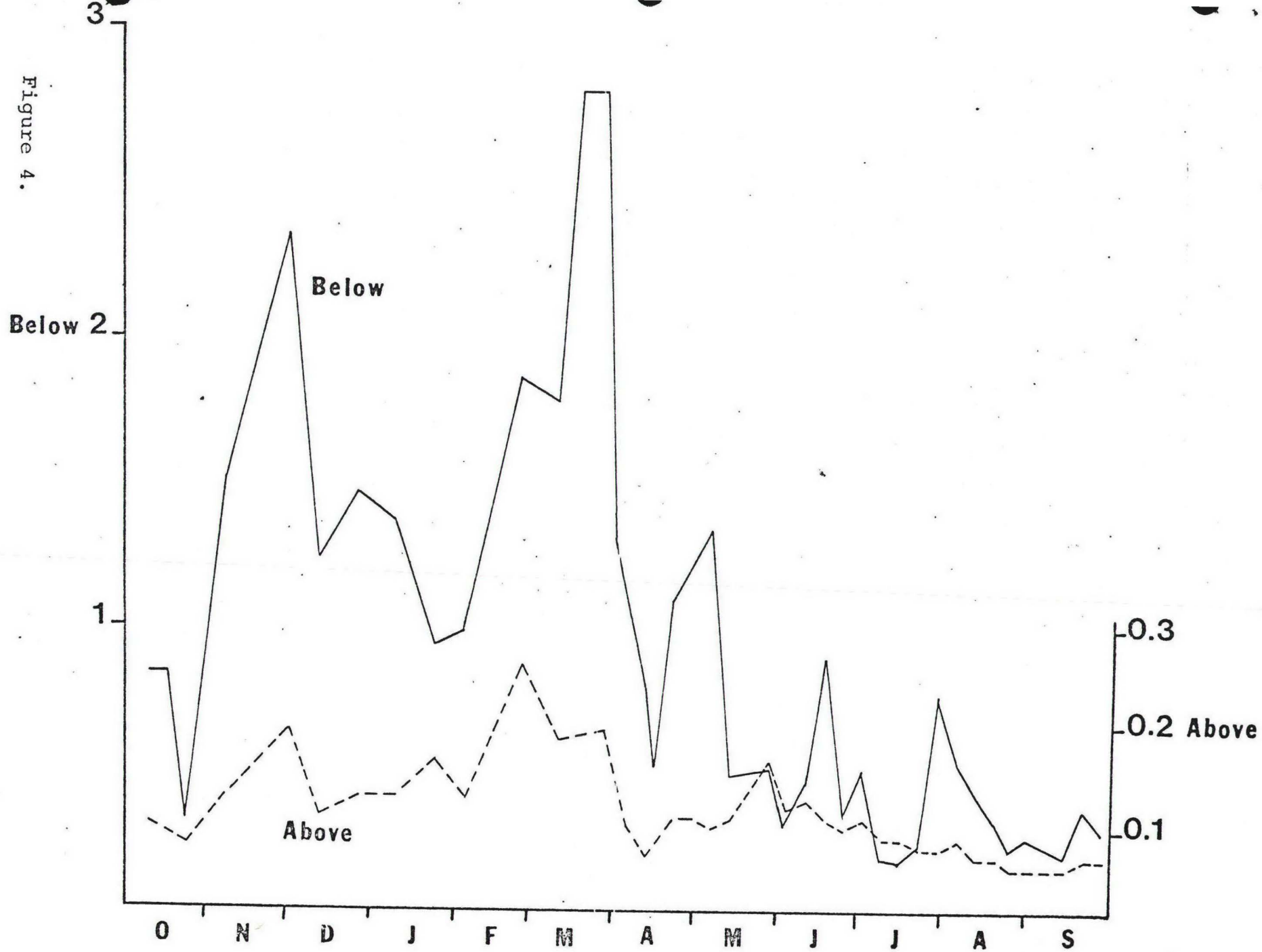


Figure 5.

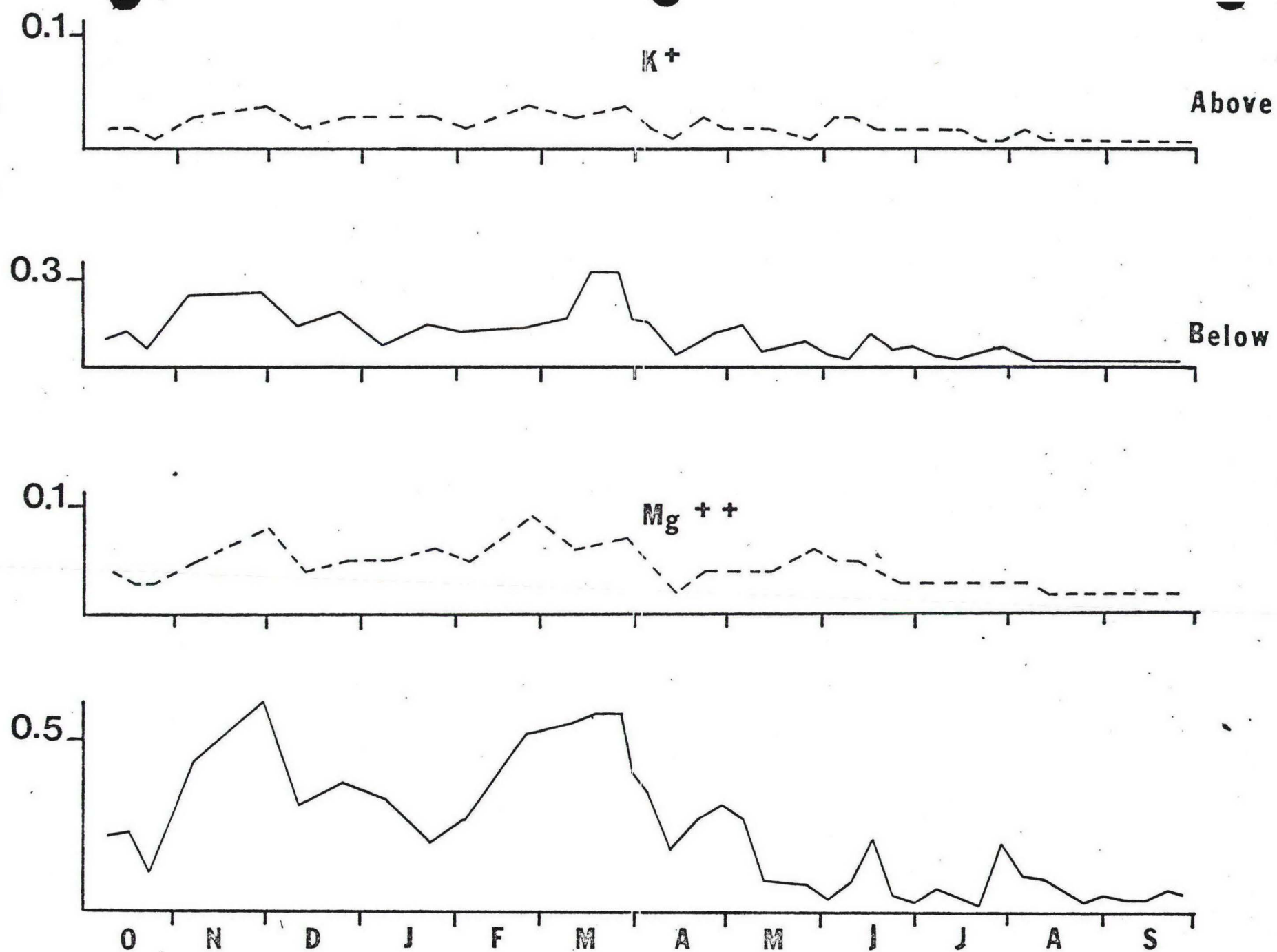
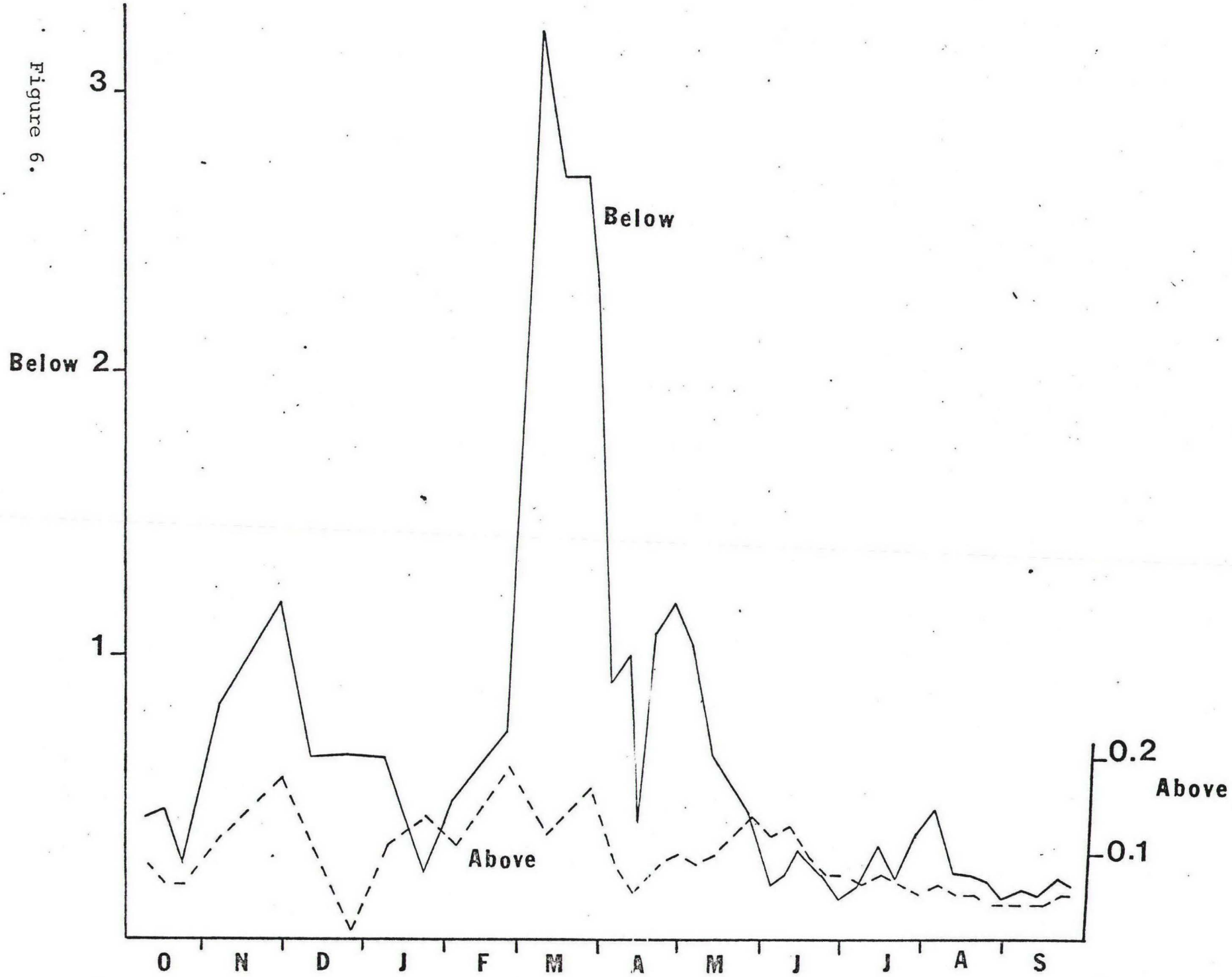


Figure 6.



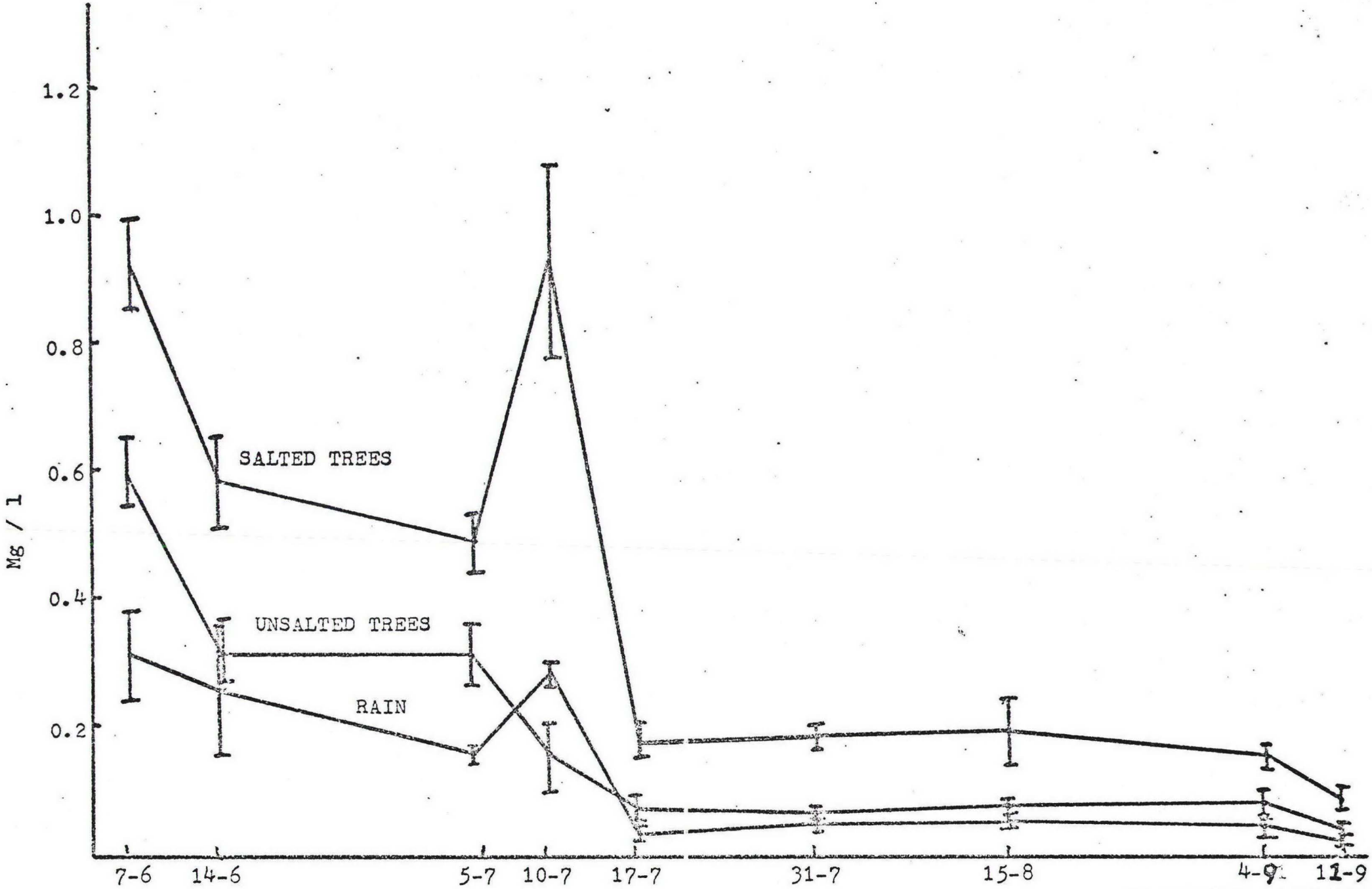


Figure 7.